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A Study on Energy Tax Reform for Carbon Pricing Using an Input-Output Table for the Analysis of a Next-Generation Energy System

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Abstract: Carbon pricing, such as a carbon tax, is an invisible hand that leads to the construction of a sustainable low-carbon society, and precise analysis of the impact of carbon pricing on each sector of the economy is indispensable for its design. In this study, an equilibrium price model based on the 2015 input-output table was used for the analysis of next-generation energy systems (2015 IONGES) and the effect of the introduction of a carbon tax on the price of the industrial sector was assessed. Based on the existing energy-related tax system in Japan, the introduction of a carbon tax is regarded as an increase in the tax for global-warming countermeasures (TGWC) in the petroleum and coal tax (PCT). While existing energy-related taxes are designed to place a relatively heavy burden on the transportation sector, tax reform of the petroleum and coal tax has a relatively large effect on raising prices in energy-conversion and energy-intensive sectors. As a result, the reform of the energy-related tax may promote the introduction of energy-saving technology and decarbonization technology, both in the transportation sector and in a wider range of sectors, and may work to correct the unfairness of the tax burden between sectors.

Keywords: carbon tax; equilibrium price model; input-output table; fairness of tax burden

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1. Introduction

According to Arimura and Matsumoto [1], after the Paris Agreement entered into force, the role of carbon pricing, such as via a carbon tax or an emission trading scheme, attracted attention all over the world once again. Although countries have created such policies to mitigate carbon emissions, the effectiveness of those policies has not been sufficiently analyzed. In particular, policy assessments and evaluations in the Asian region including Japan lag far behind those in North America and Europe.

The carbon tax was first introduced in Japan in 2012, but was set at a low level. Then, in August 2021, the Government of Japan's Central Environment Council's Subcommittee on the Utilization of Carbon Pricing [2] presented views on a carbon tax for the realization of carbon neutrality and green growth. It is necessary to increase the carbon tax in stages to show a strong price signal toward carbon neutrality in the future, which will help promote innovation in decarbonization. However, it is important to consider the speed of technological development and clarify the relationship between carbon pricing and existing energy tax systems. As Arimura and Matsumoto [1] pointed out, experimental studies on the effects of tax systems are indispensable for the policy and institutional design of effective new energy-tax systems.

Energy was first taxed in Japan in 1904. A consumption tax was levied on petroleum, which was a necessity for lighting at that time, to raise war expenses for the Russo-Japanese War. The petroleum consumption tax continued for postwar management after the Russo-Japanese War, but was abolished in 1923 in exchange for other taxes. Subsequently, the use of petroleum shifted from lighting to fuel for automobiles. In 1937, when the relationship between Japan and China deteriorated and a wartime regime was in place, a gasoline tax was introduced as a national fuel policy. The tax system was abolished in 1943 with the enactment of the Petroleum Monopoly Law, but was re-established in 1949 after World War II as a general source of revenue to compensate for the shortage of postwar fiscal revenue. Subsequently, with the rapid spread of automobiles, road maintenance became an urgent task. In 1953, all gasoline tax revenue was used for road maintenance [3].

Subsequently, the power development promotion tax and petroleum and coal tax were established in 1974 and 1978, respectively, as energy measures after the oil crisis. Currently, energy-related taxes in Japan include a gasoline tax (national tax), local gasoline tax (national tax), oil gas tax (national tax), light oil take-back tax (prefectural tax), aircraft fuel tax (national tax), petroleum and coal tax (national tax) and power source development promotion tax (national tax). Of these taxes, four taxes, ranging from gasoline tax to light oil take-back tax, were financial resources used for road maintenance. However, due to the improvement in road maintenance levels, these taxes were converted into general financial resources from FY2009. The remaining aircraft fuel tax, petroleum and coal tax and power development promotion tax are specific financial resources used for airport maintenance and noise prevention, to ensure a stable supply of energy and power sources and to uphold nuclear safety measures, respectively.

A carbon tax was levied in Japan to promote a reduction of CO_2 emissions from fossil fuels by utilizing the economic incentives of taxation, the "tax for global warming countermeasures (TGWC)" created in the 2012 tax reform. The TGWC was introduced in addition to the existing petroleum and coal tax collection scheme, which involves all fossil fuels. Figure 1 shows the relationship between petroleum and coal taxes and the TGWC. As shown in this figure, the tax rate per CO_2 emission unit differs between fossil fuels for the existing petroleum and coal tax portion, which has the purpose of upholding a stable energy supply. In addition to the petroleum and coal tax, the energy-related taxes mentioned above are relatively high for automobile fuel, for historical reasons. Even with the same fossil fuel, the tax rate per CO_2 emission unit differs depending on the application [4]. Kojima and Asakawa [5] have reported that an energy tax reform based on the carbon content of energy carriers may improve the mitigation efficiency of carbon pricing.

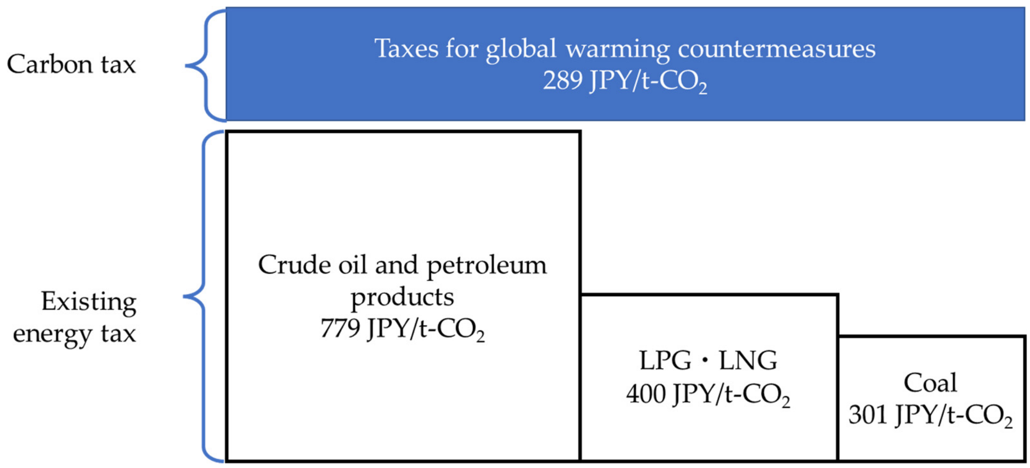

Figure 1. Tax rate per CO_2 emission unit (JPY/t-CO_2). Source: Ministry of the Environment [4].

The effective carbon tax rate per ton of CO_2 emissions from fossil fuels is low in Japan [5]. A document from the Ministry of the Environment of Japan [6] presents a more detailed review of the energy tax per ton of CO_2 emissions from fossil fuels based on the country. To give an example, the tax rate for heavy oil (for industrial use) was 17,400 JPY/t-CO_2 in Denmark and 1100 JPY/t-CO_2 in Japan. The tax rate for gasoline, which has a relatively high tax rate in Japan, was 35,400 JPY/t-CO_2 in Denmark and 24,200 JPY/t-CO_2 in Japan. However, in Japan, where natural resources are scarce, the energy price before taxation is high. A comparison of the total price of fossil fuels and the tax rate per ton of CO_2 emissions revealed that the rate for heavy oil (for industrial use) was 39,500 JPY/t-CO_2 in Denmark and 24,900 JPY/t-CO_2 in Japan, and its ratio to gasoline was 88,200 JPY/t-CO_2 in Denmark and 62,800 JPY/t-CO_2 in Japan. Considering the energy price itself, the disparity in figures (energy price + energy tax) between the two countries is somewhat narrow. As the introduction of a carbon tax is discussed based on the country internationally, it is necessary to consider the difference in the price of fossil fuels based on the difference in the resource reserves of each country.

While there is no doubt that carbon taxes should be introduced to create a strong price signal toward carbon neutrality, the issues mentioned above (a balance with the existing energy tax system based on the historical background and differences in international resource prices) pose many challenges to the design of carbon tax systems. It is urgent that we solve these issues and form a social consensus to establish a strong carbon tax system.

Therefore, the following analysis was conducted: (1) The effect of increasing the carbon tax rate in Japan was analyzed, which is currently internationally low. In addition, (2) the effects of energy tax reforms to correct the tax rate disparity were analyzed on the basis that the tax rate per unit of CO_2 emissions differed between fossil fuels in Japan's petroleum and coal taxes. (3) The extent to which these tax effects were reduced was also estimated by introducing renewable energy. Based on these results, we propose a more effective institutional design for carbon pricing in Japan.

In the next section, previous studies on carbon tax using an input-output model and other methods are reviewed. Section 3 specifies the analytical method, and Section 4 describes our database. Section 5 provides the estimation results. Based on this, an effective energy-related tax design for carbon pricing in Japan is discussed. Finally, Section 6 summarizes the paper.

2. Literature Review on the Method

The objective of carbon pricing policies, such as carbon taxes, is to promote decarbonization innovation. To increase the social acceptance and effectiveness of the carbon tax, it is better to deepen the carbon pricing policy to match the speed of innovation. Therefore, to formulate evidence-based policies on carbon pricing, analysis of the effects of renewable energy innovations, energy management and decarbonization, and an analysis of the effects of introducing carbon taxes, should be combined. Input-output tables enable technological analysis by describing the inputs required for the production activity of a sector in detail. Input-output analysis also allows the spillover effect of technological changes in some sectors to be analyzed on the economy as a whole via the relationship that the output of one sector has with input in another sector. Two types of spillover analysis models use input-output tables: the physical model and the (dual) price model [7].

The analytical formula for the physical model of the effect of introducing a carbon tax is as follows:

$$\mathbf{b} = \mathbf{E} \cdot (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}, \quad (1)$$

where $\mathbf{b}$ is a column vector, the elements are the CO_2 emissions of each sector, $\mathbf{E}$ is a carbon intensity matrix, $(\mathbf{I} - \mathbf{A})^{-1}$ is a Leontief inverse matrix (a matrix in which each element shows a direct and indirect spillover effect of one unit of final demand for each good on the economy as a whole) and $\mathbf{f}$ is the final demand vector. From Equation (1), the CO_2 emissions caused by the final demand for each sector in the economy as a whole may be calculated; by multiplying this by the carbon tax rate per unit of CO_2, the amount of carbon tax included in one unit of the final demand for goods produced in each sector may be calculated.

The analytical formula for the price model of the effect of introducing a carbon tax is as follows:

$$\mathbf{p} = \left(\mathbf{I} - \mathbf{A}'\right)^{-1}(\mathbf{v} + \Delta\mathbf{v}), \quad (2)$$

where **p** is a column vector, the elements are the price indices of each sector, $\left(\mathbf{I}-\mathbf{A}'\right)^{-1}$ is the transposed Leontief inverse matrix, and ($\mathbf{v}$ + $\Delta\mathbf{v}$) is a column vector that shows the value-added rate and its change. When all elements of $\Delta\mathbf{v}$ are zero (i.e., when the value-added rate of each sector is at the current level), the value of all elements of the column vector **p** on the left side is 1. The calculation result of Equation (2) shows the rate of change (%) in the price of goods in each sector when the value-added rate changes from the current level by $\Delta\mathbf{v}$. Indirect taxes, such as carbon taxes, are one of the factors that cause a change in the value-added rate ($\Delta\mathbf{v}$).

Equation (1) of the physical model is used to analyze the amount of carbon tax paid in the entire supply chain for the production of each good from the supplier's viewpoint. Equation (2) of the price model is used to analyze how much the price of each good changes due to the increase in the carbon tax from the consumer's viewpoint. Equations (1) and (2) are in a dual relationship, and if all levied carbon taxes are correctly passed on to the next stage, they provide the same result.

Previous studies using Equation (1) for the physical model include Morgenstern et al. [8], who examined the effect of the near-term impact on domestic manufacturing industries of both upstream (economy-wide) and downstream (electric power industry only) carbon mitigation policies, such as a carbon tax. Grainger and Kolstad [9] estimated the incidence of carbon prices induced by a cap-and-trade program or carbon tax in the context of the US in the early 2000s. Sugino et al. [10] analyzed the effects of carbon pricing on Japan's industrial sector and examined the impact of a rebate program. Jiang and Shao [11] estimated the distributional effect of a carbon tax on households in various income groups in Shanghai, China. Using the interprovincial input-output table in China, Wu et al. [12] reported a gap in CO_2 emission responsibilities between producers and consumers in different provinces and concluded that a carbon tax burden-sharing scheme should be designed. Renner [13] examined the welfare effects of different carbon tax rates on the income distribution in Mexico, which recently introduced a carbon tax. Sugino [14] focused on the effective carbon rate and estimated the effects of carbon policies that increase the effective carbon rate in Japan. Washizu and Nakano [15] analyzed the effects of different carbon taxation methods and examined how the introduction of renewable energy reduces the carbon tax burden. Yan and Yang [16] showed that household inequality may not have intensified in Guangdong, where carbon pricing is progressive. Using a multi-regional input-output analysis, Chen et al. [17] suggested that a carbon tax should be embodied in commodity prices to facilitate the development of a low-carbon interprovincial trade structure.

The use of Equation (2) as the price model is based on the following studies. In Japan, when the discussion on carbon tax was just beginning, Fujikawa [18] estimated the effect of a carbon tax predicted in the future on the increase in the price of consumer goods. Kameoka and Arimura [19] estimated the effect of TGWC introduced in Japan at that time on the increase in the price of consumer goods. Both studies revealed that the introduction of a carbon tax heavily increased the price of consumer goods for income-bearing households and residents in cold regions. Similarly, Phungrassami and Usubharatana [20] and Saelim [21] estimated the effect of a carbon tax introduced in Thailand on the increase in the prices of consumer goods and assessed changes in household welfare. Ma et al. [22,23] analyzed how changes in the carbon tax levied on energy affect the prices of other goods using network theory.

In the physical model, the absolute levied carbon tax may be calculated based on the CO_2 emissions generated in the entire supply chain of each production process. The advantage of the physical model is that it accurately measures the tax amount to be borne in the future, even in areas where a carbon tax has not yet been introduced. Another advantage of the physical model is that it may be integrated with engineering research, such as the measurement of the carbon footprint and analysis of the effects of the introduction of renewable energy. In research that focuses more on engineering, model analysis of real prices has been performed simultaneously using a hybrid input-output table consisting of elements measured in different units of quantity and price [24,25]. In the price model, the effect of introducing a carbon tax is assessed based on the rate of increase relative to the current price; therefore, it is suitable to assess existing policy effects. In addition, the network analysis of price-increase spillovers using the price model [22,23] is interesting. Nakano and Yamagishi [26] used the life cycle assessment (LCA) database rather than input-output tables to assess the impact of a carbon tax on product prices in Japan.

In this study, the price model of input-output analysis was used to assess the policy effect of reforming Japan's current energy-related tax scheme. As input-output analysis can describe the energy consumption structure of each sector classified in detail, the current energy-related tax scheme is accurately reflected in our analysis. Moreover, we have used a newly-developed input-output table in our analysis by adding the renewable energy sectors to the 2015 input-output table published by the Ministry of Internal Affairs and Communications of Japan. Using this new table, we analyzed how the introduction of renewable energy would change the policy effect of reforming the energy-related tax scheme. The novelty of this study is that the actual energy-related tax scheme is described in detail, and that the effect of the introduction of renewable energy on the reform of the scheme is analyzed. Additionally, using the price model of input-output analysis, the spillover process of price increase is also observed, and an ideal way to reform the energy-related tax is considered. The results will help businesses predict changes in their product and raw material prices due to rising energy-related tax rates. They will also help policymakers develop indicators for assessing the increased burden on households of rising prices and the fairness of tax burdens between industries. Section 5 shows the rate of change in the price index for consumers, to evaluate the increase in household burden through price increases due to the increase in energy-related tax rates.

Kojima and Asakawa [5] describe the marginal abatement cost (MAC) and explicit carbon pricing (ECP) approaches for estimating the desired carbon price level. This study includes a real carbon tax in the price model; thus, it is based on the ECP approach. MAC research attempts to estimate carbon prices technically, based on the cost of decarbonization technology. Kojima and Asakawa [5] point out that the MAC is likely to give higher estimation results because it does not fully account for the dynamic process or social effects of technology dissemination. Huang et al. [27] also found that the MAC is more reliable by ranking the values of options relative to the baseline, rather than focusing on the absolute value of individual measures. However, to assess the relationship between carbon pricing and the introduction of new technologies such as carbon dioxide capture, utilization and storage (CCUS), it is important to develop an input-output model incorporating the MAC. This will be the subject of future research.

3. Model

Using an equilibrium price model based on an input-output table, the price increase that can occur due to the introduction of a carbon tax was assessed. Equation (2) in the review section does not distinguish between the prices of domestic and imported goods; however, this study assessed changes in the prices of domestic goods. According to the equilibrium price model (Equation (3)), changes in the price of domestic goods may be represented by changes in the value-added coefficient and changes in the price of imported goods. The value-added coefficient is the gross value added per unit of production value.

$$\Delta\mathbf{p^d} = \left[\mathbf{I} - (\mathbf{I} - \hat{\mathbf{M}})\mathbf{A}'\right]^{-1}(\hat{\mathbf{M}}\mathbf{A}'\Delta\mathbf{p^m} + \Delta\mathbf{v}), \quad (3)$$

where $\mathbf{\Delta p^d}$ is a vector of changes in domestic goods prices, $\mathbf{I}$ is the unit matrix, $\hat{\mathbf{M}}$ is the import coefficient matrix (import value per domestic demand value), $\mathbf{A}'$ is the transposed matrix of the input coefficient matrix, $\mathbf{\Delta p^m}$ is the vector of change in import goods prices and $\mathbf{\Delta v}$ is the vector of change in the value-added coefficient.

In this study, it was assumed that there was no change in the price of imported goods due to the introduction of the carbon tax, and only the value-added coefficient increased.

In other words, the increase in energy cost per unit of production was an increase in the value-added coefficient. This study assumes that the burden of carbon tax is passed on through domestic product prices, but does not assess whether exported domestic products affect the prices of imported products. All increases in energy prices due to carbon taxes were passed on to the product price. It should be noted that the trigger was the rise in production costs in the fuel consumption sector, not the price rise in the primary energy production sector. It was assumed that the tax would be levied when refined petroleum products were sold to the consumer sector and not when the petroleum refinery products sector accepted crude petroleum. In addition, a decrease in demand and the effect of substitution due to the increase in prices were not considered. The model also did not include feedback from final-demand sectors, such as households. This study assumes the following short-term economies: The increase in energy prices does not immediately change the technological input structure as represented by the input coefficient in the input-output table. In other words, there is no substitution between factors of production, such as raw materials, labor and capital in production activities. Additionally, consumers do not immediately change their consumption structure, as shown by the unchanged composition ratio of goods in the final demand. Therefore, changes in the industrial sector (e.g., energy prices) do not affect consumer behavior and production activities in the short run. One way to deal with the medium- to long-term economy that alleviates these assumptions is to conduct the analysis with a general equilibrium model. However, it is not realistic to create a multi-sector economic model with detailed sector classification, as in this study. A variable response to these assumptions will be investigated in a future study.

The input coefficient of the input-output table is the average value for an industrial sector as a whole. Even in the same industrial sector, the input coefficients on a company or establishment basis differ, depending on the goods produced, number of employees, sales, location and so on. Therefore, the impact of rising energy prices on the prices of goods produced by companies and establishments in the same industrial sector differ. Due to the existence of such heterogeneity in energy consumption, the results calculated in this study need to be interpreted with caution.

Energy-related taxes in Japan include the petroleum and coal tax (PCT), gasoline taxes, local gasoline taxes, oil gas taxes, aircraft fuel taxes, light oil take-back taxes and power source development promotion taxes that are levied on electricity (Table 1). The PCT is levied on crude petroleum, coal, liquified natural gas (LNG) and imported petroleum refinery products, and is levied at the top of the supply chain. In addition to the main tax rate in the PCT, the tax for global warming countermeasures (TGWC) was gradually added to this tax in 2012 and was raised to the final tax rate in 2016. The tax rate for the TGWC is 289 JPY per 1t-CO_2, which is 760 JPY/kL, 780 JPY/t and 670 JPY/t in terms of the unique units of petroleum (crude petroleum, imported petroleum refinery products), gas (liquified petroleum gas (LPG), LNG) and coal, respectively.

Table 1. Energy-related taxes in Japan (JPY/unit).

	Unit	**Energy-Related Taxes Excl. the PCT**	**Petroleum and Coal Tax (PCT)**	**Incl.**		**Simulation Scenario ***			
				Main Tax Rate	**TGWC**	**S1**	**S2**	**S3**	**S4**
Crude petroleum	kL		2800	2040	760	2620	7860	13,100	26,200
Petroleum refinery product (imported)	kL		2800	2040	760	2620	7860		26,200
Gasoline	kL	53,800							
Jet fuel oil	kL	18,000							
Light oil	kL	32,100							
LPG (imported)	t		1860	1080	780	2700	8100	13,500	27,000

Table 1. *Cont.*

	Unit	Energy-Related Taxes Excl. the PCT	Petroleum and Coal Tax (PCT)	Incl.		Simulation Scenario *			
				Main Tax Rate	TGWC	S1	S2	S3	S4
LPG (for motor vehicle)	t	17,500							
LNG	t		1860	1080	780	2700	8100	13,500	27,000
Coal	t		1370	700	670	2330	6990	11,650	23,300
Electricity	10^6 kWh	375,000							

* The tax rate for global warming countermeasures (TGWC) for simulation is assumed to be 1000 JPY/t-CO_2 (S1), 3000 JPY/t-CO_2 (S2), 5000 JPY/t-CO_2 (S3), or 10,000 JPY/t-CO_2 (S4). The CO_2 conversion coefficients for "crude petroleum and petroleum refinery product", "LPG and LNG", and coal are 2.62t-CO_2/kL, 2.7t-CO_2/t, and 2.33t-CO_2/t, respectively. Sources: Ministry of Finance [28] and Ministry of the Environment [4] for CO_2 conversion coefficients.

In this study, based on discussions in a subcommittee of the Ministry of the Environment [29], the TGWC was considered a type of carbon tax, and the effect of raising the TGWC tax rate to 1000 JPY, 3000 JPY, 5000 JPY or 10,000 JPY per 1 ton of CO_2 emissions was examined. In addition, tax exemption and refund measures were applied to specific fields in the TGWC, and it was assumed that these measures would continue even when the TGWC tax rate was raised.

The TGWC is an addition to the main tax levied at a different tax rate for each fuel, and the tax rate per carbon is not equal between fuels when the PCT is considered as a whole. Therefore, there are criticisms that even if the TGWC tax rate is raised, it cannot be regarded as imposing a carbon tax. The case in which the PCT was replaced by a carbon tax with the same tax rate per carbon was also assessed. In other words, the price increase was determined if the main tax rate for gas and coal was adjusted to that for petroleum (779 JPY/t-CO_2).

What can be done to curb the rise in product prices due to the introduction of a carbon tax? One such measure is a fuel source change. For example, if fossil fuels for power generation could be replaced with renewable energy, it would be possible to curb the increase in electricity prices due to a carbon tax. In this study, the effect of suppressing the increase in product prices due to the introduction of a carbon tax was assessed by substituting thermal power generation with renewable energy power generation (Equation (4)).

$$\Delta\mathbf{p}^{renew} = \mathbf{B}^{renew}\Delta\mathbf{v}^{renew}, \tag{4}$$

where $\boldsymbol{\Delta}\mathbf{p}^{\boldsymbol{renew}}$ is the vector of the restraining effect on product price increase due to renewable energy power generation, $\mathbf{B}^{\boldsymbol{renew}}$ is the submatrix extracted from $\mathbf{B}$ for renewable energy power generation ($\mathbf{B} = [\mathbf{I} - (\mathbf{I} - \hat{\mathbf{M}})\mathbf{A}']^{-1}$) and $\boldsymbol{\Delta}\mathbf{v}^{\boldsymbol{renew}}$ is the difference vector of energy cost increase per unit production due to a carbon tax between thermal power generation and renewable energy power generation.

Renewable energy generation for business use, in 2015, accounted for approximately 0.5% of all power sources. Therefore, the effect of suppressing an increase in product prices owing to the introduction of a carbon tax should be limited. However, as renewable energy power generation is expected to continue to spread, if the share of renewable energy power generation increases to 30%, the rise in product prices will be suppressed. Thus, how the effect may change was also assessed.

4. Data

A 2015 input-output table was developed for the analysis of next-generation energy systems (IONGES), which incorporated renewable energy sectors that existed in 2015. In addition to the thermal, nuclear and hydropower generation sectors, power generation equipment/facility construction sectors and power generation sectors for the 15 types of renewable energy (Table 2) were included in IONGES. The total gross domestic production (CT) of the power generation sectors in IONGES was equal to the total CT of the power generation sectors in the input-output table developed by the Ministry of Internal Affairs and Communications in Japan (MIC-IO). However, the power generation equipment/facility construction sector in IONGES had a different concept from the power facility construction sector in the MIC-IO. The former included the power generation equipment and civil engineering work required for the construction of the power generation facility, while the latter included only the civil engineering work on the power generation facility. The total CT of the power generation equipment and facility construction sectors in IONGES was equal to the sum of the CT of the power generation sectors and the material amount of the power facility construction sector included in the fixed capital formation of the final demand in MIC-IO. See Appendix A for how to create the 2015 input-output table for analysis of the next-generation energy system.

Table 2. Power plant specifications used for estimation in the 2015 IONGES.

	Capacity		Generation (MWh/Year)	Utilization Rate	Unit Cost for Construction (Thousand JPY/kW)	Operation Cost (Thousand JPY/kW /Year)	Purchase Price under the FIT (JPY/kWh)	Service Life
Solar power (for residential use)	4	kW	**4**	0.12	369.0	3.6	34.00	30
Solar power (for business)	1200	kW	**1472**	0.14	307.5	6.0	27.50	30
Onshore wind power	20,000	kW	**35,040**	0.2	300.0	6.0	22.00	20
Offshore wind power	150,000	kW	**394,200**	0.3	565.0	22.5	36.00	20
Small- and medium-sized hydropower	199	kW	**1046**	0.6	800.0	75.0	25.00	40
Flash-type geothermal	30,000	kW	**218,124**	0.83	790.0	33.0	26.00	40
Binary-type geothermal	50	kW	**394**	0.9	1230.0	48.0	40.00	40
Woody biomass (30,000 kW)	30,000	kW	**217,016**	**0.826**	**296.7**	Operation costs are estimated based on each source	24.00	40
Woody biomass (5000 kW)	5000	kW	**34,164**	**0.780**	**530.0**		32.00	40
Woody biomass (2000 kW)	1990	kW	**13,474**	**0.773**	**713.6**		40.00	40
Methane fermentation (raw garbage)	50	t/day	**785**	0.300	**8034.6**		39.00	30
Methane fermentation (sewage sludge)	161	m^3/day	**1486**	0.355	**535.8**		39.00	30
Methane fermentation (livestock manure)	95	t/day	**1977**	**0.752**	**2650.0**		39.00	30
Waste incineration (large-sized city)	600	t/day	**26,685**	0.650	**4744.3**		17.00	40
Waste incineration (medium-sized city)	300	t/day	**13,350**	0.650	**5785.9**		17.00	40

Source: Cost Verification Committee [30] for capacity and service life. FY2015 Procurement Price Calculation Committee [31] for utilization rate, operation cost, and purchase price under the feed-in tariff (FIT) scheme. Power plant specifications for binary-type geothermal and biomass power generation are based on each source [32]. Bold indicates that the value is calculated backward.

5. Results and Discussion

5.1. Impact of Raising the TGWC in the PCT on Prices

To determine the macro impact of the TGWC increase in the PCT on prices, the price index was examined, which is a weighted average of prices by goods according to the composition of private consumption expenditure in the 2015 IONGES. Although this price index is valued at the producer's price, it is similar to the consumer price index. Assuming that the price level in 2015 was 1, energy-related taxes accounted for 0.69%. If the TGWC was raised to 1000 JPY/t-CO_2 (scenario S1), the price would increase by 0.12%. If the TGWC was further increased, the price would rise by 0.45% for 3000 JPY/t-CO_2 (scenario S2), 0.79% for 5000 JPY/t-CO_2 (scenario S3) and 1.62% for 10,000 JPY/t-CO_2 (scenario S4).

Next, price changes by industry sector were examined (Table 3). The top 10 sectors with the highest proportion of energy-related taxes at the price level in 2015 were the transport sectors, such as self-transport (17.41%), road transport (4.21%) and air transport (2.72%). The top 10 sectors also included energy-conversion sectors, such as methane fermentation gas power generation (livestock waste) (4.94%), commercial thermal power generation (3.39%), coal products (2.73%) and private power generation (thermal power) (2.28%). Other energy-intensive sectors, such as the miscellaneous mining industry (5.51%), petrochemical basic products (3.53%) and wooden chips (for power generation) (2.37%), were also included.

Table 3. Proportion of energy-related taxes in price in 2015 (top 10 sectors).

Rank	Sector	Proportion
1	Self-transport	17.41%
2	Miscellaneous mining industry	5.51%
3	Electricity (methane fermentation gas (livestock waste))	4.94%
4	Road transport (except self-transport)	4.21%
5	Petrochemical basic products	3.53%
6	Electricity (thermal power)	3.39%
7	Coal products	2.73%
8	Air transport	2.72%
9	Wooden chips (for power generation)	2.37%
10	Private power generation (thermal power)	2.28%

Source: Authors' estimation.

When the TGWC was raised to 1000 JPY/t-CO_2 (scenario S1), the price increase rate of coal products was the highest at 2.73% (Table 4). This was followed by the energy-conversion sectors, such as commercial thermal power generation (2.20%) and private power generation (thermal power) (1.92%). The gas and heat supply sectors also ranked high at 1.43%. Following this, the rate of increase in prices of basic energy-intensive petrochemical products was as high as 1.64%, and the other chemical product sectors, such as organic chemical products (0.73%), synthetic fibers (0.64%) and synthetic resins (0.59%) were also at the top. Self-transport (0.71%), which had the highest ratio of energy-related taxes to price, also had a high rate of price increases. In addition, energy-intensive pig iron and crude steel (0.58%) were included at the top. If the TGWC was further raised to 3000 JPY (scenario S2), 5000 JPY (scenario S3) and 10,000 JPY (scenario S4), the price increased in the same way in all sectors, and the relative ranking of the price increase rate did not change.

Japan's energy taxes were designed to place a relatively heavy burden on vehicle fuel, that is, on the transport sector. However, the impact of the TGWC hike on price increases was relatively greater in the energy-conversion and energy-intensive chemical sectors. This suggested that the policy option of raising the TGWC could place a relatively heavy tax burden on the transport sector, and even on the energy-conversion and energy-intensive sectors. Therefore, raising the TGWC might promote both the spread of decarbonization technologies, such as electric vehicles and fuel cell vehicles in the transportation sector, and the spread of other decarbonization technologies, such as CCUS in other energy-intensive sectors.

Table 4. Price increase due to the TGWC increase (top 10 sectors).

	Scenario S1 *		Scenario S2	
Rank	**Sector**	**Rate**	**Sector**	**Rate**
1	Coal products	2.73%	Coal products	10.39%
2	Electricity (thermal power)	2.20%	Electricity (thermal power)	8.39%
3	Private power generation (thermal power)	1.92%	Private power generation (thermal power)	7.31%
4	Petrochemical basic products	1.64%	Petrochemical basic products	6.26%
5	Gas and heat supply	1.43%	Gas and heat supply	5.46%
6	Organic chemical products	0.73%	Organic chemical products	2.78%
7	Self-transport	0.71%	Self-transport	2.69%
8	Synthetic fibers	0.64%	Synthetic fibers	2.43%
9	Synthetic resins	0.59%	Synthetic resins	2.25%
10	Pig iron and crude steel	0.58%	Pig iron and crude steel	2.22%
	Scenario S3		**Scenario S4**	
Rank	**Sector**	**Rate**	**Sector**	**Rate**
1	Coal products	18.05%	Coal products	37.20%
2	Electricity (thermal power)	14.59%	Electricity (thermal power)	30.06%
3	Private power generation (thermal power)	12.69%	Private power generation (thermal power)	26.16%
4	Petrochemical basic products	10.87%	Petrochemical basic products	22.41%
5	Gas and heat supply	9.49%	Gas and heat supply	19.56%
6	Organic chemical products	4.83%	Organic chemical products	9.95%
7	Self-transport	4.68%	Self-transport	9.65%
8	Synthetic fibers	4.22%	Synthetic fibers	8.71%
9	Synthetic resins	3.92%	Synthetic resins	8.08%
10	Pig iron and crude steel	3.86%	Pig iron and crude steel	7.96%

* The tax rate for global warming countermeasures (TGWC) for the simulation is assumed to be 1000 JPY/t-CO_2 (S1), 3000 JPY/t-CO_2 (S2), 5000 JPY/t-CO_2 (S3), and 10,000 JPY/t-CO_2 (S4). Source: Authors' estimation.

The high rate of price increase in the "self-transport" sector would promote: (1) streamlining of distribution networks using advanced technologies such as ICT, (2) outsourcing of transportation services such as the use of road freight transport and (3) introduction of low-carbon automobiles for self-transport. Thus, it may result in reduced CO_2 emissions in the entire transport sector.

5.2. Impact of Changes to the Main Tax Rate on the PCT on Prices

The effect on prices when the main tax rate for gas and coal in the PCT was adjusted to that for petroleum (779 JPY/t-CO_2) was then considered. As before, using the price index, the price level would be raised by 0.05%. If the main tax rate for gas and coal was changed and the TGWC was raised to 1000 JPY (scenario S1), the price would rise by 0.17%. In other words, the change in the main tax rate would result in an additional 0.05 points to the price increase effect of raising the TGWC. This also applied to Scenarios S2–S4.

The top four sectors with the highest rates of price increases when the main tax rates for gas and coal changed were energy-conversion sectors (Table 5). Coal products (1.78%), commercial thermal power generation (1.19%), private power generation (thermal power, 1.09%) and gas and heat supply (0.75%) were included. Following this, the iron and steel sectors (such as pig iron and crude steel (0.35%), steel products (0.25%) and cast and forged steel products (0.23%)), chemical product sectors (such as synthetic fibers (0.29%) and chemical fertilizer (0.25%)) and energy-incentive sectors (such as pulp, paper, paperboard, coated and blazed paper (0.26%)) were included.

Table 5. Price increase due to a change in the main tax rate for coal and gas (top 10 sectors, unit: %).

Rank	Sector	Rate
1	Coal products	1.78%
2	Electricity (thermal power)	1.19%
3	Private power generation (thermal power)	1.09%
4	Gas and heat supply	0.75%
5	Pig iron and crude steel	0.35%
6	Synthetic fibers	0.29%
7	Pulp, paper, paperboard, coated and glazed paper	0.26%
8	Steel products	0.25%
9	Chemical fertilizer	0.25%
10	Cast and forged steel products (iron)	0.23%

Source: Authors' estimation.

If the main tax rate for gas and coal was changed and the TGWC was increased to 1000 JPY (scenario S1), the ranking of the top sectors in the rate of price increase would change (Table 6). There would be no change in the relatively high rate of price increases in the energy-conversion sector. However, while the ranking of iron and steel sectors and that of pulp, paper, paperboard, coated and blazed paper would decline, the chemical product sectors, such as petrochemical basic products and organic chemical products, would occupy the top position. This tendency would become even stronger when the TGWC was raised further (scenarios S2–S4).

Similar to the increase in the TGWC, the change in the main tax rate in the PCT would have a significant effect on raising the price in the energy-conversion and energy-intensive sectors. Therefore, choosing a policy option that combines a change in the main tax rate for coal and gas with an increase in the TGWC could encourage the spread of decarbonization technology in a wider range of sectors.

5.3. Contribution of Renewable Energy Power Generation to Curb Price Increases Due to Energy-Related Taxes

We observed that raising the TGWC resulted in higher prices in the energy-conversion sector, among other things. One of the means to curb price increases in the energy-conversion sector is a fuel source change. For example, if fossil fuel power generation technology was replaced by decarbonized power generation technology, the tax burden on fuel should be reduced, and price increases should be suppressed. Thus, we next examined how much commercial renewable energy power generation, excluding large-scale hydropower generation, could curb price increases by substituting commercial thermal power generation.

Considering the price index, if the TGWC was raised to 1000 JPY (scenario S1), the suppressive effect of price on renewable energy power generation was 0.001%. Furthermore, if the TGWC was raised, the effect was 0.002% for 3000 JPY (scenario S2), 0.003% for 5000 JPY (scenario S3) and 0.005% for 10,000 JPY (scenario S4). Here, renewable energy power generation has an extremely small effect on suppressing price increases because renewable energy power generation for business use, excluding large-scale hydropower generation, accounted for only 0.5% in 2015.

Table 6. Price increase due to the change in the main tax rate for coal and gas, and the TGWC increase (top 10 sectors, unit: %).

	Scenario S1 *		Scenario S2	
Rank	**Sector**	**Rate**	**Sector**	**Rate**
1	Coal products	4.50%	Coal products	12.17%
2	Electricity (thermal power)	3.40%	Electricity (thermal power)	9.59%
3	Private power generation (thermal power)	3.01%	Private power generation (thermal power)	8.40%
4	Gas and heat supply	2.19%	Petrochemical basic products	6.47%
5	Petrochemical basic products	1.86%	Gas and heat supply	6.22%
6	Organic chemical products	0.94%	Organic chemical products	2.99%
7	Pig iron and crude steel	0.94%	Synthetic fibers	2.72%
8	Synthetic fibers	0.92%	Self-transport	2.71%
9	Pulp, paper, paperboard, coated and glazed paper	0.76%	Pig iron and crude steel	2.58%
10	Chemical fertilizer	0.75%	Synthetic resins	2.38%
	Scenario S3		**Scenario S4**	
Rank	**Sector**	**Rate**	**Sector**	**Rate**
1	Coal products	19.83%	Coal products	38.98%
2	Electricity (thermal power)	15.78%	Electricity (thermal power)	31.26%
3	Private power generation (thermal power)	13.78%	Private power generation (thermal power)	27.25%
4	Petrochemical basic products	11.09%	Petrochemical basic products	22.63%
5	Gas and heat supply	10.25%	Gas and heat supply	20.32%
6	Organic chemical products	5.04%	Organic chemical products	10.16%
7	Self-transport	4.70%	Self-transport	9.67%
8	Synthetic fibers	4.51%	Synthetic fibers	8.99%
9	Pig iron and crude steel	4.21%	Pig iron and crude steel	8.31%
10	Synthetic resins	4.05%	Synthetic resins	8.21%

* The tax rate for global warming countermeasures (TGWC) for the simulation is assumed to be 1000 JPY/t-CO_2 (S1), 3000 JPY/t-CO_2 (S2), 5000 JPY/t-CO_2 (S3), and 10,000 JPY/t-CO_2 (S4). Source: Authors' estimation.

According to the 6th Strategic Energy Plan [33] decided by the Government of Japan in 2021, the target is to increase the ratio of renewable energy power generation, including large-scale hydropower generation, to approximately 36–38%. Therefore, when the ratio of commercial renewable energy power generation, excluding large-scale hydropower generation, reaches 30%, the effect of curbing price increases due to the increase in the TGWC may be assessed. If the TGWC is raised to 1000 JPY (scenario S1), the suppressive effect of renewable energy power generation on price increases is 0.025%. If the TGWC is further increased, the effect is 0.057% for 3000 JPY (scenario S2), 0.090% for 5000 JPY (scenario S3) and 0.170% for 10,000 JPY (scenario S4).

When the ratio of renewable energy power generation increases to 30%, the effect of curbing price increases due to the increase in the TGWC will increase. As renewable energy is expected to become widespread in the future, renewable energy power generation is expected to mitigate price increases due to the carbon tax.

6. Conclusions

In this study, the TGWC in the PCT was regarded as a type of carbon tax and the effect of raising the TGWC on the price was assessed using the equilibrium price model and the 2015 IONGES. If the TGWC was raised to 1000 JPY/t-CO_2 (scenario S1), the prices faced by consumers would increase by 0.12%. If the TGWC was raised further, the price would increase by 0.45% for 3000 JPY (scenario S2), 0.79% for 5000 JPY (scenario S3) and 1.62% for 10,000 JPY (scenario S4). In addition, if the main tax rate of coal and gas in the PCT was adjusted to that of petroleum (779 JPY/t-CO_2), it would add an additional 0.05 points to the price increase effect of the increase in the TGWC.

In the industry sector, energy-related taxes accounted for a relatively large proportion of the prices in the transport sector. However, raising the TGWC had a relatively large effect on raising prices in the energy-conversion and energy-intensive sectors. In addition, changes in the main tax rates for coal and gas in the PCT also had a large effect on raising prices in these sectors. If the main tax rate in the PCT matched that of petroleum and the TGWC was raised, the tax burden previously biased toward the transport sector spread to the energy-conversion and energy-intensive sectors. As a result, this tax reform might help promote the introduction of energy-saving and decarbonizing technologies in a wider range of sectors and correct the tax burden unfairness between industrial sectors.

However, this evaluation was based on the following assumptions. Under the assumptions of this study, all increases in energy prices due to the carbon tax were passed on to the product price. In addition, the decrease in demand and the effect of substitution due to the rise in prices were not considered. The evaluation did not include feedback from end-demand sectors, such as households. Therefore, the price changes determined in this study should be interpreted as potential price changes, and additional consideration is required to determine actual price changes.

The purpose of a carbon tax is to encourage the introduction of energy-saving and decarbonizing technologies. If these technologies become widespread, the carbon tax burden should be reduced, and the impact on prices should be suppressed. Therefore, in the future, the effect of the introduction of new energy technologies, such as CO_2-free hydrogen and CCUS, on the price increase due to a carbon tax should be analyzed. In addition, it was confirmed that the effect of suppressing the price increase due to the carbon tax increases as the ratio of renewable energy power generation increases. Thus, the effect of the introduction of a smart management system that enables the mass introduction of renewable energy power sources on the price increase due to the carbon tax should also be analyzed in the future.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Creation of the 2015 Input-Output Table for Analysis of the Next-Generation Energy System

See Nakano and Washizu [34] for details on how to create the 2015 input-output table for analysis of the next-generation energy system.

Appendix A.1. Power Transmission and Distribution Sectors

The 2015 MIC-IO incorporated the "commercial thermal power generation" sector and the "commercial power generation (excluding thermal power generation)" sector, which also included power transmission and distribution activities. Because the role of smart grids is important in next-generation energy systems, the IONGES incorporates the power-transmission and distribution sectors separately from the power-generation sector.

According to the operating expense statements of 10 electric power companies, the J-POWER operating expense statement and the profit and loss statement of the local public enterprise, the power-transmission and distribution cost accounts for 24.43% of the sum of the power generation cost and the power-transmission and distribution cost. Therefore, the power-transmission and distribution sector was created such that the CT of the power-transmission and distribution sector equaled 24.43% of the CTs of the two commercial power-generation sectors. The input vector for the power-transmission and distribution sector was created by correcting the weighted average of the input coefficients common to the two commercial power-generation sectors. While reducing the input vector of the power-transmission and distribution sector from the two commercial power-generation sectors, all power-transmission and distribution services were allocated to the two commercial power-generation sectors. As a result, the CTs of the two commercial power-generation sectors remained unchanged compared to those in the MIC-IO.

Appendix A.2. Private Power Generation Sector

The private power-generation sector in the 2015 MIC-IO included the electricity sold to the commercial power sector. This might obscure the interpretation of the repercussion of power generation in next-generation energy systems. Therefore, the CT of the private power-generation sector was reduced by the amount of electricity sold to the commercial power sector, and the vector of input goods corresponding to the reduced CT was added to the input vector of the commercial power sector. In other words, the commercial power sector changed to directly purchase the input materials required to generate that power instead of purchasing privately generated power. To avoid distorting the original input structure of the commercial power sector, it was assumed that the source of the privately generated power to be purchased was the same as that of the commercial power sector.

Appendix A.3. Domestic Demand of the Power-Generation Equipment/Facility Construction Sector

Table A1 shows the domestic demand and composition ratio of the power-generation equipment and facility construction sector in the 2015 IONGES. In these amounts, the investment in the capital formation sector related to electric power (excluding the amounts of nuclear fuel, software and R&D) in the fixed capital matrix of MIC-IO was transferred to endogenous sectors. However, the total amount of fixed capital formation did not change because all power-generation equipment/facility construction services were supplied as fixed capital formation.

In the fixed capital matrix, "electricity" was incorporated as the capital formation sector, and "wind power generation", "solar power generation" and "other renewable energy power generation" were also incorporated as the included amount of "electricity". The domestic demand for the construction of power generation, transmission and distribution facilities for existing electric power was obtained by subtracting the included amount of each mode of power generation from the investment amount of "electricity". The domestic demand for onshore wind power-generation equipment and facility construction was the total investment in "wind power generation" in the fixed capital matrix. The domestic demand for the construction of solar power-generation equipment/facility for business was the total investment amount of "solar power generation" in the fixed capital matrix plus the total investment amount of small-scale commercial solar power-generation equipment/facility. The total investment in "other renewable energy power generation" in the fixed capital matrix corresponded to the total investment in the construction of power-generation equipment/facility for woody biomass (30,000 kW and 5000 kW classes) and replenishment wells of flash-type geothermal energy.

Table A1. Domestic demand of the power-generation equipment/facility construction sector in the 2015 IONGES.

	Million JPY	Composition Ratio
Existing electric power incl. transmission and distribution facilities	2,236,601	37.3%
Solar power (for residential use)	318,342	5.3%
Solar power (for business)	2,737,509	45.7%
Onshore wind power	120,254	2.0%
Small- and medium-sized hydropower	79,463	1.3%
Flash-type geothermal	-	0.0%
Replenishment well of flash-type geothermal	40,549	0.7%
Binary-type geothermal	10,778	0.2%
Woody biomass (30,000 kW)	34,593	0.6%
Woody biomass (5000 kW)	82,510	1.4%
Woody biomass (2000 kW)	1406	0.0%
Methane fermentation (raw garbage)	13,972	0.2%
Methane fermentation (sewage sludge)	588	0.0%
Methane fermentation (livestock manure)	13,479	0.2%
Waste incineration (large-sized city)	124,124	2.1%
Waste incineration (medium-sized city)	179,879	3.0%
Total	5,994,048	100.0%

Source: Authors' estimation.

However, it was not possible to identify where the material investment amount of each power-generation equipment/facility construction for residential use for solar power, small- and medium-sized hydropower, binary type-geothermal, woody biomass (2000 kW class), methane fermentation (raw garbage, sewage sludge and livestock manure) and waste incineration (large- and medium-sized cities) were contained in the fixed capital matrix of the MIC-IO. Therefore, the amount corresponding to these was not deducted from the fixed capital formation. The total fixed capital formation and total domestic demand of IONGES were larger than the corresponding values in the MIC-IO by the investment amount in these power-generation equipment/facility construction sectors.

The domestic demand for each renewable energy power-generation equipment/facility construction sector, excluding the total investment in the generation equipment/facility's construction for onshore wind power and replenishment wells of flash-type geothermal energy, was calculated by multiplying the increments of newly installed and certified capacity (kW) under the feed-in tariff (FIT) scheme from 2014 to 2015 by the construction unit price in Table 2.

Appendix A.4. Domestic Demand of the Commercial Power-Generation Sector

Table A2 presents the domestic demand and composition ratio of the commercial power-generation sector in the 2015 IONGES. These values were derived by dividing the domestic demand for commercial power generation (excluding thermal power generation) by the composition ratio of nuclear power, hydropower and "renewable power generation" in the electric power business handbook by the Japan Electric Association. In addition to the domestic demand and composition ratio of the renewable power-generation sector, the capacity of "renewable power generation" in the electric power business handbook was divided by the composition ratio of renewable energy power generation calculated from the installed and certified capacity (cumulative) under the FIT scheme.

Table A2. Domestic demand of the commercial power-generation sector in the 2015 IONGES.

	Million JPY	**Composition Ratio**	**Composition Ratio for Renewable Energies**
Thermal power	15,827,578	89.389%	
Nuclear power	156,840	0.886%	
Hydropower (large-sized)	1634,249	9.230%	
Solar power (for residential use)	7888	0.045%	8.99%
Solar power (for business)	22,204	0.125%	25.30%
Onshore wind power	4359	0.025%	4.97%
Offshore wind power	12	0.00007%	0.01%
Small and medium-sized hydropower	1530	0.009%	1.74%
Flash-type geothermal	69	0.00039%	0.08%
Binary-type geothermal	64	0.00036%	0.07%
Woody biomass (30,000 kW)	7176	0.041%	8.18%
Woody biomass (5000 kW)	1487	0.008%	1.70%
Woody biomass (2000 kW)	48	0.00027%	0.05%
Methane fermentation (raw garbage)	9	0.00005%	0.01%
Methane fermentation (sewage sludge)	7	0.00004%	0.01%
Methane fermentation (livestock manure)	67	0.00038%	0.08%
Waste incineration (large-sized city)	19,570	0.111%	22.30%
Waste incineration (medium-sized city)	23,255	0.131%	26.50%
Total	17,706,412	100.000%	

Source: Authors' estimation.

Appendix A.5. Input Coefficient Vector of the Power-Generation Equipment/Facility Construction Sector

Each input coefficient vector was created using the same method as the 2011 IONGES [15,32]. Table 2 shows the scale and unit cost of the power-generation facility used to create the input vector for the renewable energy power-generation equipment/facility construction sector. However, the cost composition of solar power generation (for residential use and business) and wind power generation, where power-generation costs and technological trends have significantly changed, were updated.

Table A3 shows the cost composition of solar power generation (for residential use and business) and equipment/facility construction that reflects the parts prices in 2015. The cost composition of photovoltaic (PV) modules was 39.7% for residential use and 36.5% for business. Compared to the assumptions in the 2011 IONGES, the price of residential PV modules significantly dropped.

Table A3. Cost composition of solar power-generation equipment/facility construction.

For Residential Use				**For Business**			
		Details of BOS				**Details of Others**	
Module	0.397			Module	0.365		
Invertor	0.129					Invertor	0.610
BOS (balance of system)	0.082	Panel mount	0.477	Panel mount	0.102		

Table A3. *Cont.*

For Residential Use				For Business			
		Details of BOS				**Details of Others**	
		H-shaped steel	0.111	Others	0.086	H-shaped steel	0.083
		Junction box	0.191			Junction box	0.142
		Cubicle	0.155			Cubicle	0.116
		Data-measuring device	0.042			Data-measuring device	0.032
		Uninterruptible power system	0.001			Uninterruptible power system	0.001
		Display device	0.023			Display device	0.017
				PCS	0.090		
				Connection cost	0.018		
Installation cost	0.188			Installation cost	0.330		
Margin	0.203			Others	0.010		
Total	1.000		1.000		1.000		1.000

Sources: The 24th meeting of the FY2016 Procurement Price Calculation Committee [35] on solar power generation for residential use, the 23rd meeting of the FY2016 Procurement Price Calculation Committee [36] and the 20th meeting of the FY2015 Procurement Price Calculation Committee [37] on solar power generation for business.

According to "PV shipment in Japan" by the Japan Photovoltaic Energy Association (JPEA), the number of domestic shipments in 2015 was 2.70 GW for PV modules produced in Japan and 5.16 GW for modules produced overseas. By comparing the Japanese module cost and the cost outside Japan based on the "Current Survey of Production" by the Ministry of Economy, Trade and Industry (METI), the website column by the Renewable Energy Institute in Japan [38] and the Corporate Goods Price Index (2015 base) by the Bank of Japan, the difference between domestic and foreign prices of PV modules was assumed to be 3.14-fold (the ratio of domestic prices to import prices). The import ratio to domestic demand was assumed to be 37.8%.

Based on recent changes in technological trends, the cost composition of wind turbines, which was a prerequisite for creating input vectors for the wind power-generation equipment/facility construction sector, was updated. According to the Japan Society of Industrial Machinery Manufacturers (JSIM) [39], the powertrain of wind turbines before 2000 was mainly a combination of a geared speed increaser and induction generator. Later, when 2–3 MW generators became mainstream, powertrains combining permanent magnet synchronous generators, full converters and gearless direct drives were adopted. In the 2011 IONGES, it was assumed that onshore wind turbines with small generators would have geared wind turbines, while offshore wind turbines with large generators would have gearless wind turbines. However, in a low-speed direct drive, the generator is a multipole machine so the diameter and weight increase. Therefore, 5–8 MW machines adopt technology that combines a permanent magnet synchronous generator, a full converter and a medium-speed gear drive to reduce the size and cost. As a result, the number of wind turbines with gears is increasing even for offshore wind power, which is becoming larger.

Therefore, in the 2015 IONGES, both onshore and offshore wind power were assumed to have wind turbines with gears, and the cost composition was changed to the value obtained by JSIM [39]. Table A4 shows the cost composition used to create the input vector for the wind power-generation equipment/facility construction sector in the 2015 IONGES.

According to the JSIM [39], the numbers of wind-power generators introduced in FY2015 are 56 MW for domestic wind turbines and 191 MW for overseas wind turbines. By comparing the Japanese turbine cost and the average cost outside Japan, in the IEA Wind TCP Annual Report 2015 [40], the difference between the domestic and foreign prices of wind turbines is assumed to be 4.02-fold (the ratio of domestic prices to import prices). The import ratio of domestic demand is assumed to be 45.9%.

Table A4. Cost composition of wind power-generation equipment/facility construction.

Onshore Wind Power		Offshore Wind Power	
Tower	11.8%	Tower	6.6%
Blade	11.2%	Blade	6.3%
Speed increaser (gear)	10.1%	Speed increaser (gear)	5.6%
Others	8.9%	Others	5.0%
Convertors	3.0%	Convertor	1.7%
Pitch and yaw mechanism	3.0%	Pitch and yaw mechanism	1.7%
Generator	2.4%	Generator	1.3%
Transformer	2.4%	Transformer	1.3%
Casting product	1.8%	Casting product	1.0%
Bearing	1.8%	Bearing	1.0%
Forged product	1.8%	Forged product	1.0%
Control device	1.2%	Control device	0.7%
Grid interconnection	14.5%	Interconnection/submarine cable/substation, etc.	12%
Survey cost and design	2.9%	Project cost	2%
Transportation and assembly	23.4%	Transportation and installation	19%
		Construction and financing cost	12%
		Foundation work	22%
Total	100.0%	Total	100.0%

Source: The Japan Society of Industrial Machinery Manufacturers [39].

Appendix A.6. Input Coefficient Vector of the Power-Generation Equipment/Facility Construction Sector

The input coefficient vector of the renewable energy power-generation sector was created using the same method as in the 2011 IONGES [15,32]. The operation and maintenance costs per unit shown in Table 2 were divided by the input goods, and the input coefficient was estimated by dividing each input amount by the power-generation amount.

In the 2015 IONGES, as in the 2011 IONGES, both commercial and renewable energy power were converted into monetary amounts by the same producer's price. In addition, the difference between the purchase price under the FIT scheme and the producer's price of renewable energy power was shown as a negative value in the row vector of "difference from FIT" provided in the value-added vector. That is to say, it adopted the same table format as for the ordinary subsidy. However, in the three woody biomass power-generation sectors, it was assumed that a part of the "difference from FIT" was also used to subsidize the purchase of input goods, such as fuel. The subsidy allocated to the fuel purchase of woody biomass power plants (30,000 kW and 5000 kW classes) was expressed as the output of "wood chips (for power generation)" to the government expenditure.

The MIC-IO also incorporated the "wood chips" sector, but the "wood chips (for power generation)" sector in the 2015 IONGES used only unused wood, such as thinned wood, branches and leaves. It was assumed that the goods were different from the "wood chips" in the MIC-IO. Though there are cases where normal wood chips are used for woody biomass power generation, the amount was presumed to be small. Therefore, in the 2015 IONGES, it was assumed that only "wood chips (for power generation)" derived from unused wood were included in the woody biomass power-generation sector.

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